What's Between Stars?

Interstellar Gas

- *There is gas between stars of night.*
- *Some of it dark, some of it bright…*

Phase of ISM

- Interstellar gas – often called ***Interstellar Medium*** (ISM) exists in different phases.
  - ***Coronal gas***: very rarefied, T > 1 million K; a tiny fraction by mass, about 20-50% by volume.
  - ***Diffuse interstellar gas***: several atoms per cubic cm, T ~ 10,000 K; about 50% by mass, 50-80% by volume.
  - ***Molecular gas***: made out of H_2 molecules; dense (>1,000 molecules per cm^3), T~10-30 K; about 50% by mass, a tiny fraction by volume.

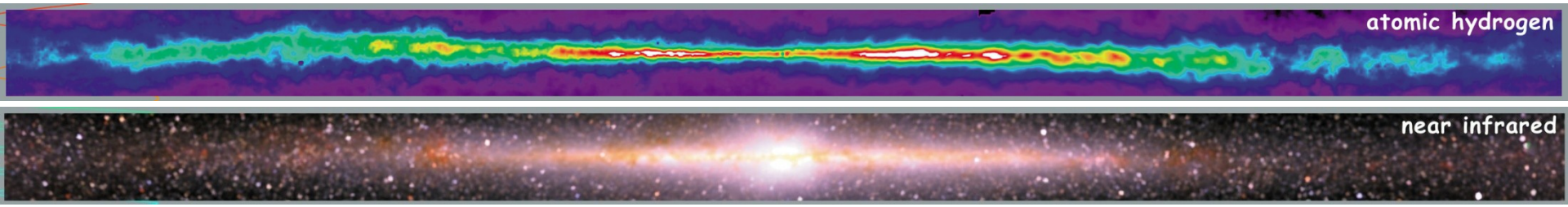
Coronal Gas

- Very tenuous, so very had to see. Result of supernova explosions.
- We actually do not know very well how much volume it takes.
- Essentially irrelevant.

Model, not a real photograph!

Diffuse Interstellar Gas (DIG)

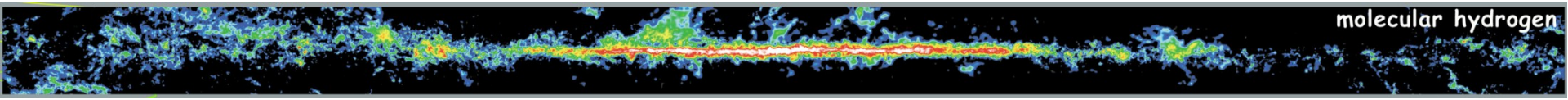
- The main gas component in the Galaxy.
- Detected by the 21cm radio line of hydrogen. This is a great line to work with, since the whole universe is transparent to it!



- The diffuse gas is mostly located in the disk, close to the central plane (***the plane of the Galaxy***). The gaseous disk is even narrower than the stellar disk (except on the outskirts).

Molecular Gas

- More than 99% of it is H_2 (molecular hydrogen).
- Most of the molecular gas is very dense – it has densities of 100 – 10,000 molecules per cm^3. This is about 10 – 100 lower than the density of the best laboratory vacuum.



- The molecular gas is very close to the Galactic plane – the thickness of the molecular disk is only 70 pc (atomic gas ~150 pc, stars ~ 300 pc).

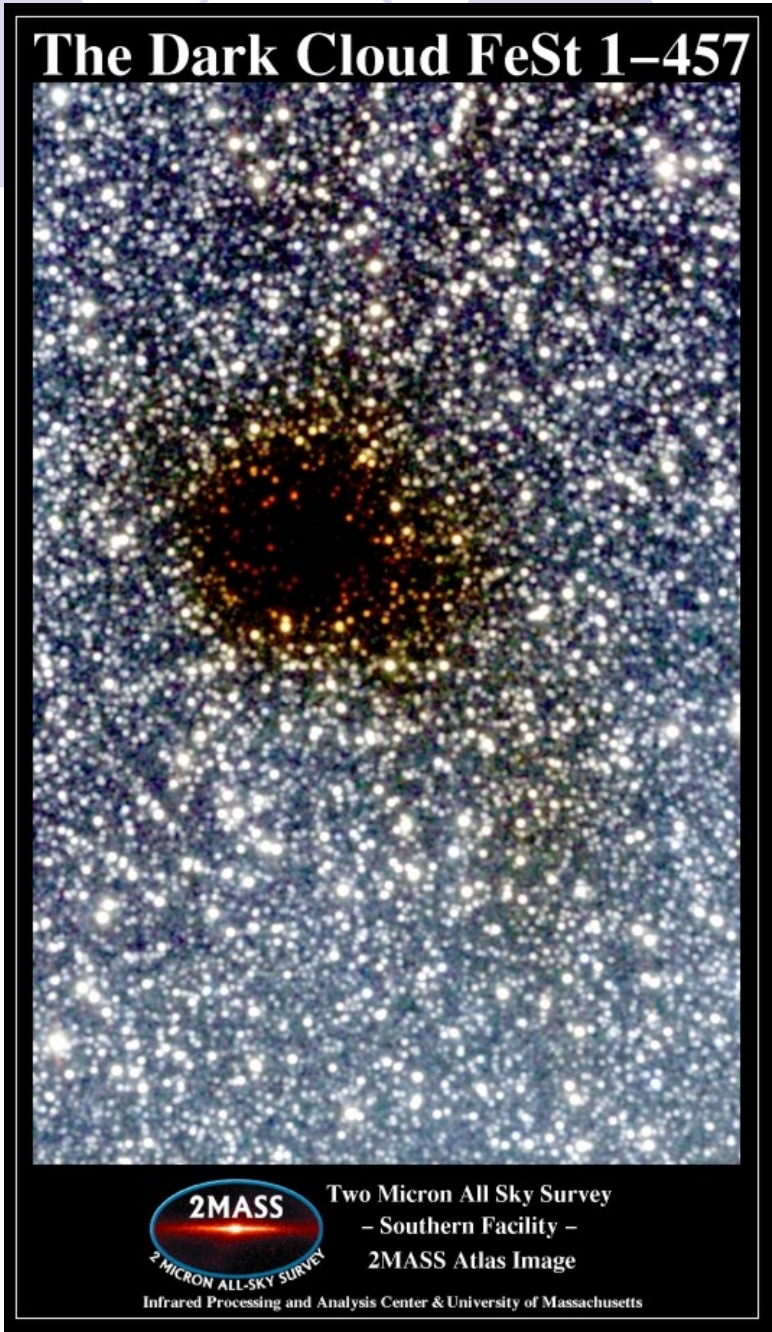
Molecular Hydrogen

- Fortunately for astronomers, hydrogen molecules are very simple, and only absorb UV radiation. They are absolutely transparent in the visible light.
- If they were not, we would not be able to see very far along the galactic plane in the visible light.

- Oops! Have I gotten it wrong?

Dark Clouds

- Molecular gas comes in separate ***dark clouds***. These clouds are dark, because they absorb most of the visible light.
- First detected by Johannes Hartmann (1865 - 1936) in 1904 using spectroscopy.
- He detected it using…
  - **A**: emission lines.
  - **B**: absorption lines.

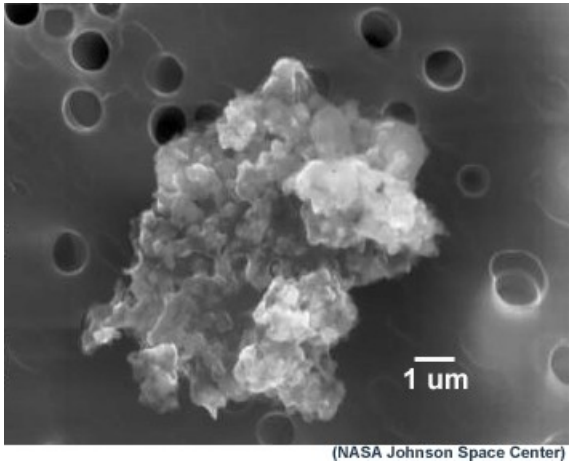


Why Are H_2 Clouds Dark?

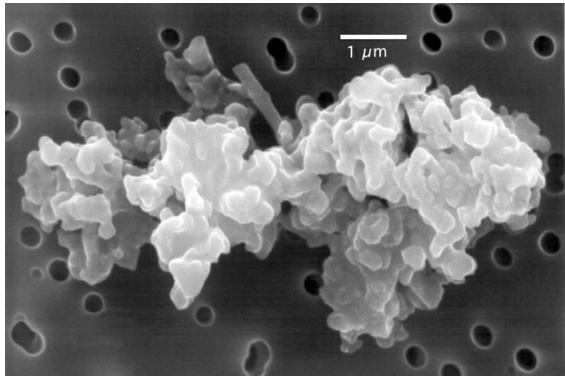
- **A**: Because molecular hydrogen absorbs the visible light very efficiently.
- **B**: Because they are located at night.
- **C**: Because there are no stars inside to light them up.
- **D**: Because molecular clouds are very cold.
- **E**: Because they contain something else that absorbs the visible light.

Cosmic Dust: Astronomer's Bane

- All molecular clouds contain cosmic dust. Dust is made of particles of various sizes, from a few molecules to sand-like grains.
- Dust particles have random shapes.
- Most of the dust is very cold: 10 – 50K (-440 – -370^{o}F).

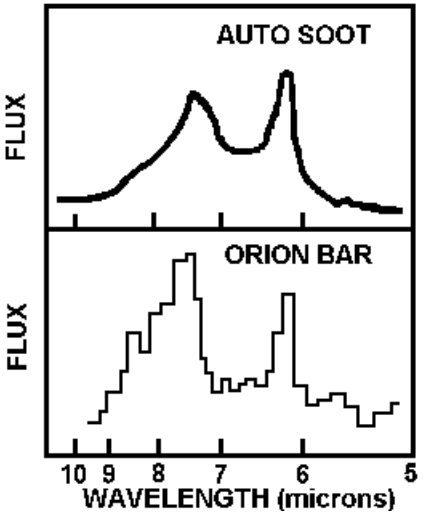


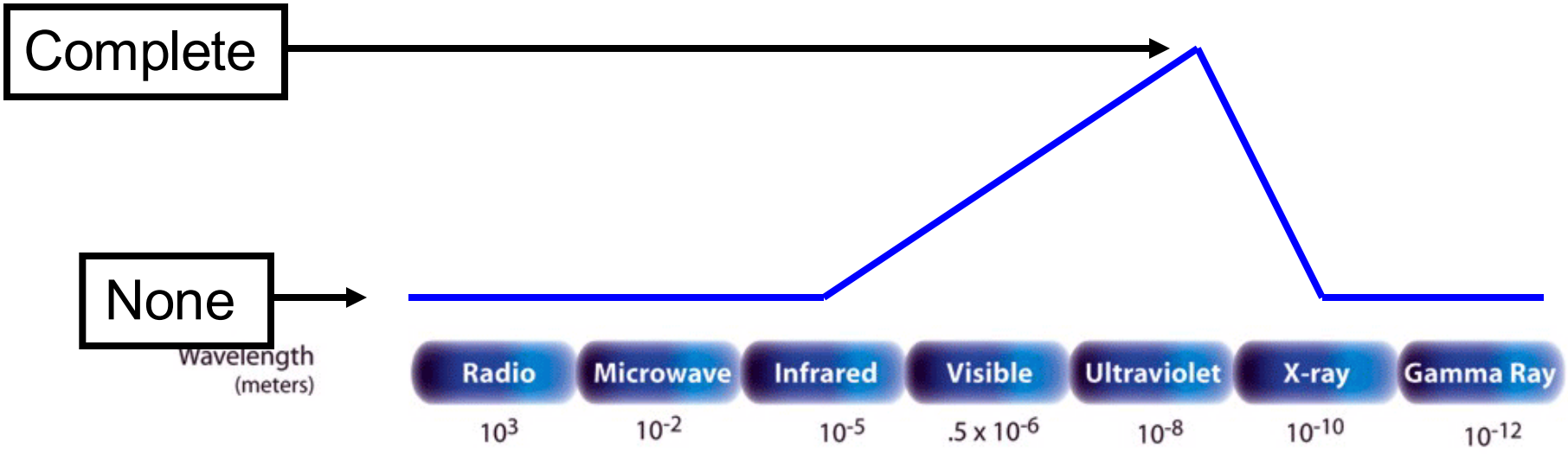
(NASA Johnson Space Center)



Dust Properties

- Chemically, these particles belong to 2 distinct types:
  - ***Silicates***: sand (Si,O,H)
  - ***Graphites***: soot (C,O,H)
- Light absorption:





Abundance of Cosmic Dust

- In the Milky Way, dust makes about 1% of the mass of molecular clouds. What about other galaxies?

	LMC	*SMC*
Size:	8 kpc	3 kpc
Total mass:	$2.0 \times 10^{10}\ M_\odot$	$6.0 \times 10^{9}\ M_\odot$
Disk mass:	$4 \times 10^{9}\ M_\odot$	$1 \times 10^{9}\ M_\odot$
Rotation speed:	70 km/s	50 km/s
Metallicity:	0.5	0.2

- What fraction of molecular clouds is in dust in LMC?
  - **A**: 2%
  - **B**: 1%
  - **C**: 0.5%
  - **D**: none

Why Is Plume Red?

- **A**: Because redwood is being burned.
- **B**: Because fire is red, it pains the smoke red too.
- **C**: Because soot absorbs blue light more than red.
- **D**: Because it is a sunset, and the Sun is red at sunset.
- **E**: Because the smoke is hot, it glows red.

Formation of Cosmic Dust

- Dust forms by molecules and smaller dust particles agglomerating together in collisions.
- To agglomerate efficiently, the gas has to have temperature of 1,000 – 3,000 K.
- At T = 5,000 K the collisions are so hard, the dust particles are destroyed instead.
- Where does cosmic dust form?
  - **A**: Molecular clouds
  - **B**: Supernova explosions
  - **C**: Atmospheres of Red Giants
  - **D**: Diffuse interstellar gas

Galactic Ecology

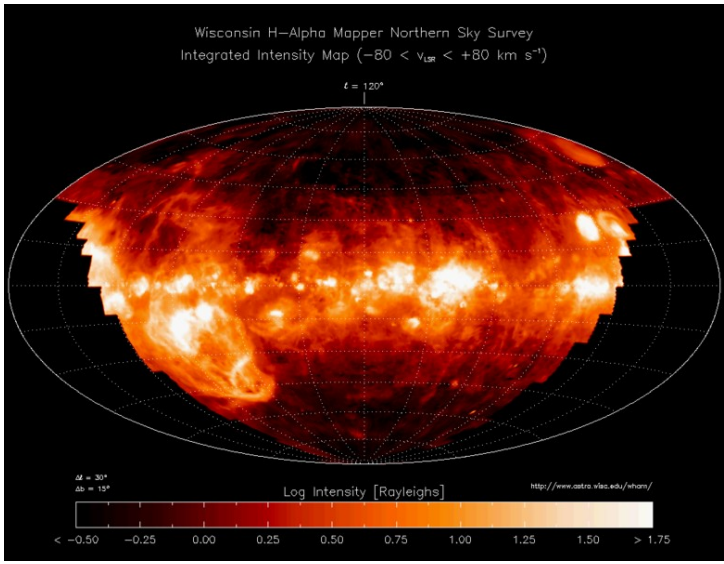
- Why are there all these phases? There must be a reason that gas takes all these different forms.
- What matters for gas? Unless it rotates very fast (and none of the interstellar gas does), only gravity and pressure matter.
- ***Gravity + Pressure = Density + Temperature***
- Temperature is determined by ***heating*** and ***cooling*** of the gas.
- If gas cools, it gets denser, if it heats up, it gets rarefied.

How Does Gas Cool?

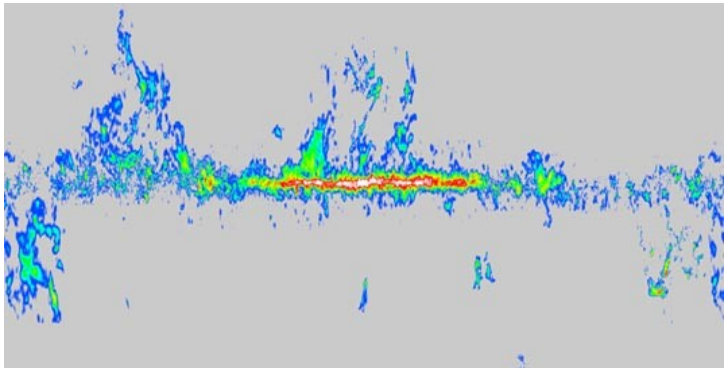
- As gas cools, its gets colder, so it loses energy. But shouldn't the energy be conserved?
  - **A**: No, the conservation of energy does not apply to gas.
  - **B**: The energy is radiated away.
  - **C**: Thermal energy goes into kinetic: colder gas moves faster (winds are stronger in winter).
  - **D**: Thermal energy is converted into gravitational energy as the gas cloud collapses.

Ups and Downs in Cosmic Gas Life

- Gas cools by glowing – i.e. emitting radiation.
- ***Coronal gas:*** emits X-rays.



- ***Diffuse gas:*** emits visible light and near IR.



- ***Molecular gas***: emits far IR and microwave.

Where Does Molecular Gas Go?

- As the gas in molecular clouds keeps cooling, it gets denser, and denser, and denser…
- What happens to it eventually?
  - **A**: It becomes liquid and then solid.
  - **B**: It keeps getting denser all the time, never stops.
  - **C**: Eventually, it forms a heating source inside and stops cooling.
  - **D**: Eventually, when it gets really dark and cannot radiate anything, it stops cooling.

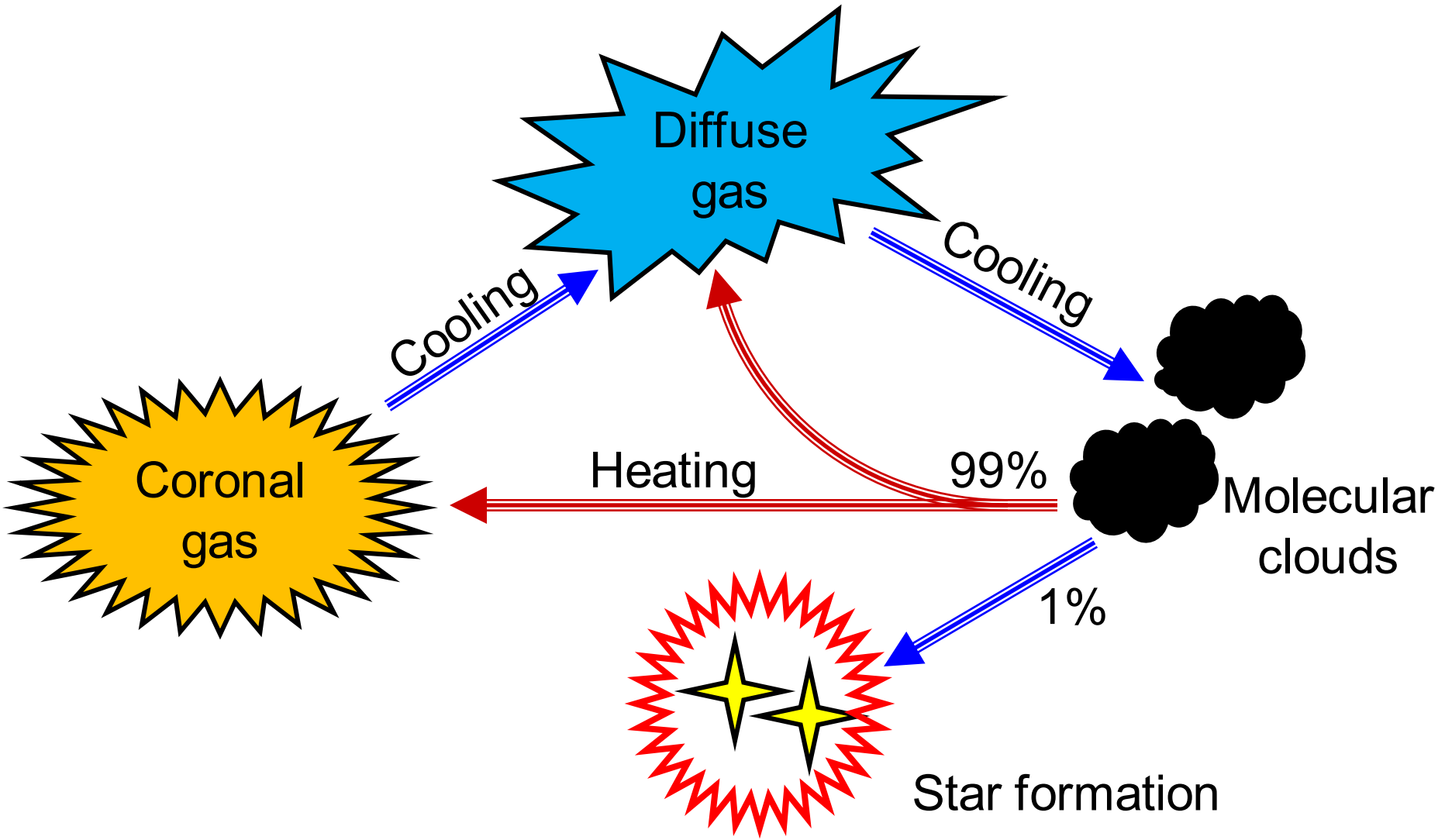
The danger of winter sports, or what happens when molecular gas is too careless with cooling…

Star Formation

- Stars form in molecular clouds (and from molecular gas).
- “What do stars do best?” – you know that!
- Only 1% of gas needs to go into stars, for stars to be able to boil the rest of the cloud away.

- But this is a topic for another story…

Closing the Loop



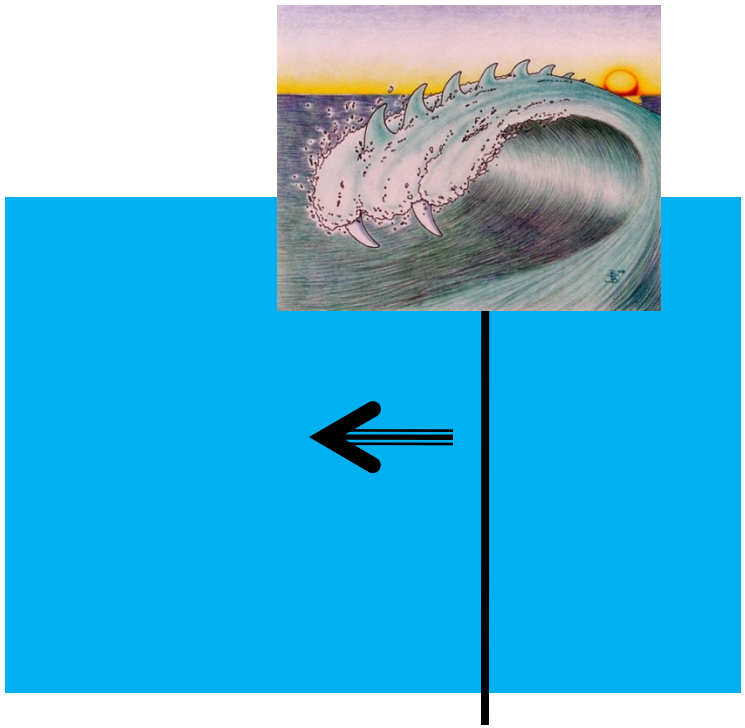
Painting by Stars

What do you see?

- Spiral arms.
- Cold dust is located along the inner edge.
- Heated dust is just outside it.
- Young (=blue) stars are outside hot dust.
- Diffuse gas is even further.

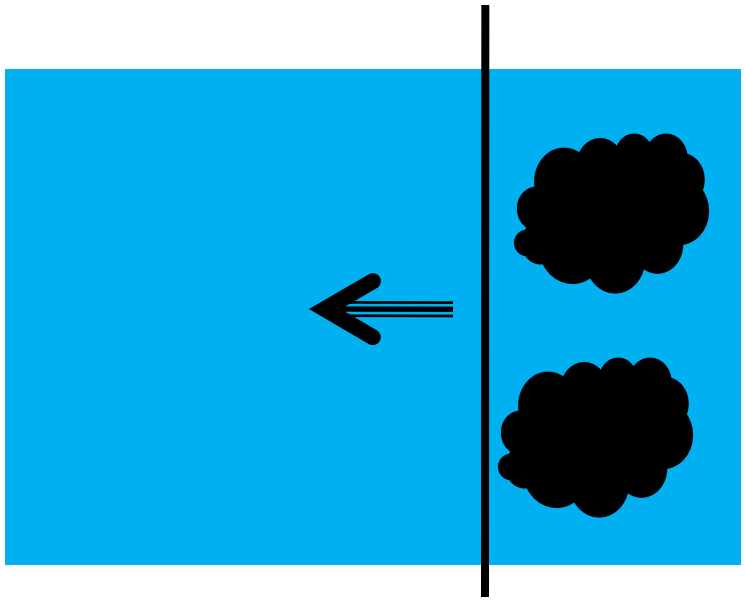
Spiral Density Waves

- Spiral arms are ***density waves***: they are not static objects, gas flows through them in a cycle of galactic ecology:
  A. ***Diffuse gas*** gets hit by a wave…



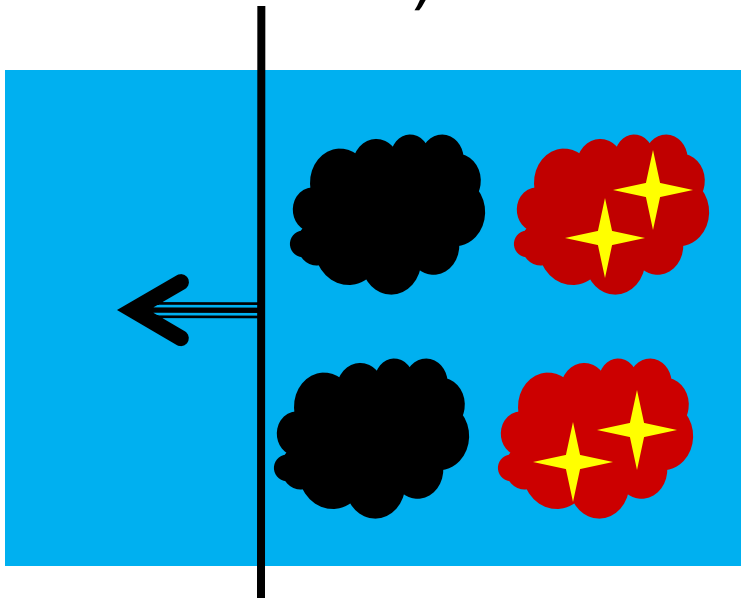
Spiral Density Waves

- Spiral arms are ***density waves***: they are not static objects, gas flows through them in a cycle of galactic ecology:
  - B. ***…***compresses, cools down, and forms cold ***molecular clouds***;



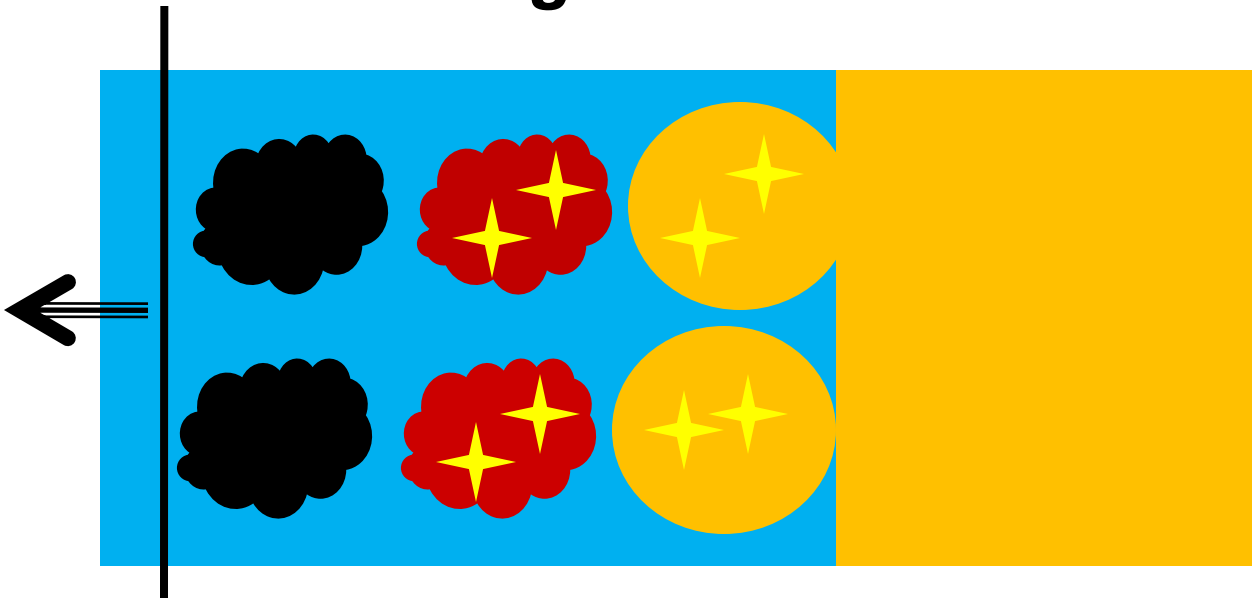
Spiral Density Waves

- Spiral arms are ***density waves***: they are not static objects, gas flows through them in a cycle of galactic ecology:
  C. ***Stars*** begin to form in molecular clouds, heating the gas and dust (but the wave goes on and on…)



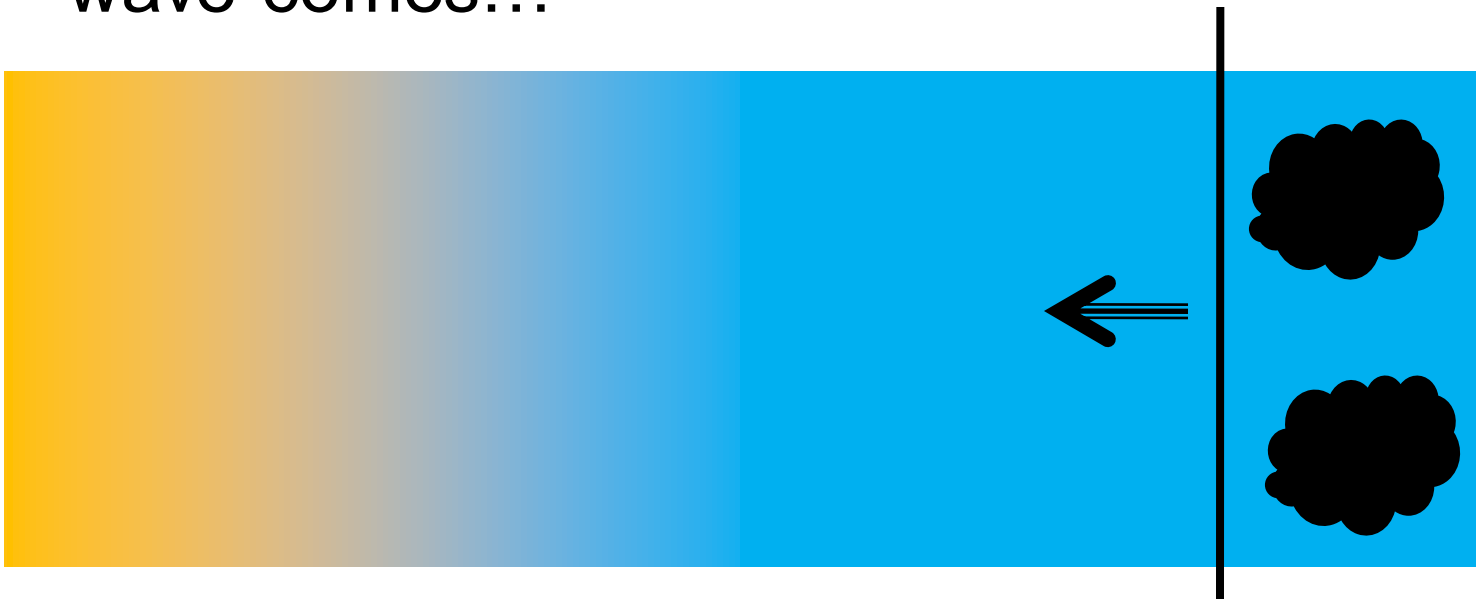
Spiral Density Waves

- Spiral arms are ***density waves***: they are not static objects, gas flows through them in a cycle of galactic ecology:
  - *D.* Eventually, molecular gas gets heated by UV radiation and supernova explosions, turning into ***coronal gas***.



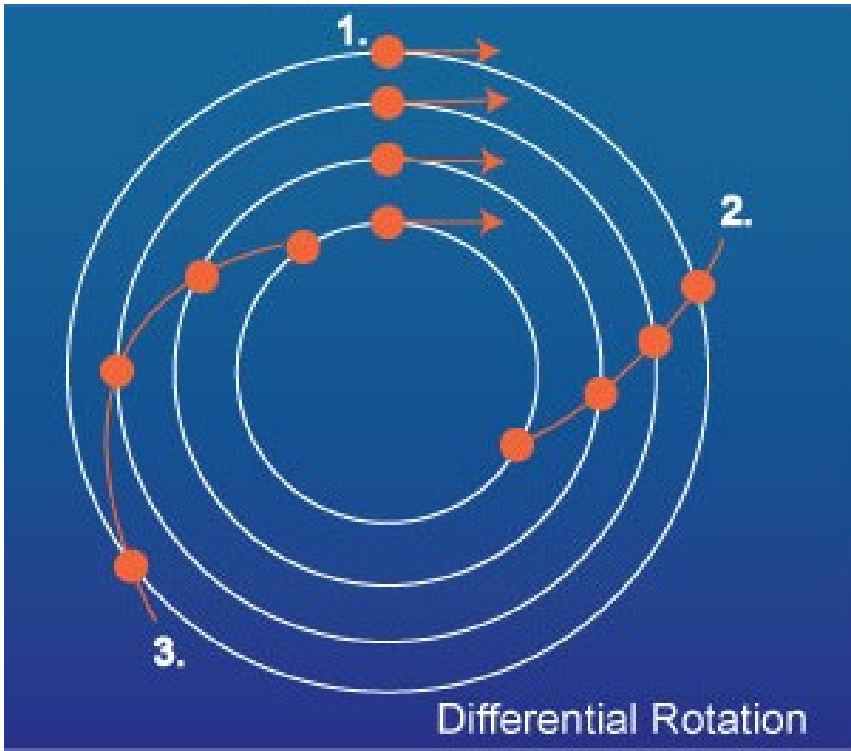
Spiral Density Waves

- Spiral arms are ***density waves***: they are not static objects, gas flows through them in a cycle of galactic ecology:
  - *E.* After the wave passed, coronal gas gradually cools into ***diffuse gas***, until the next spiral wave comes…

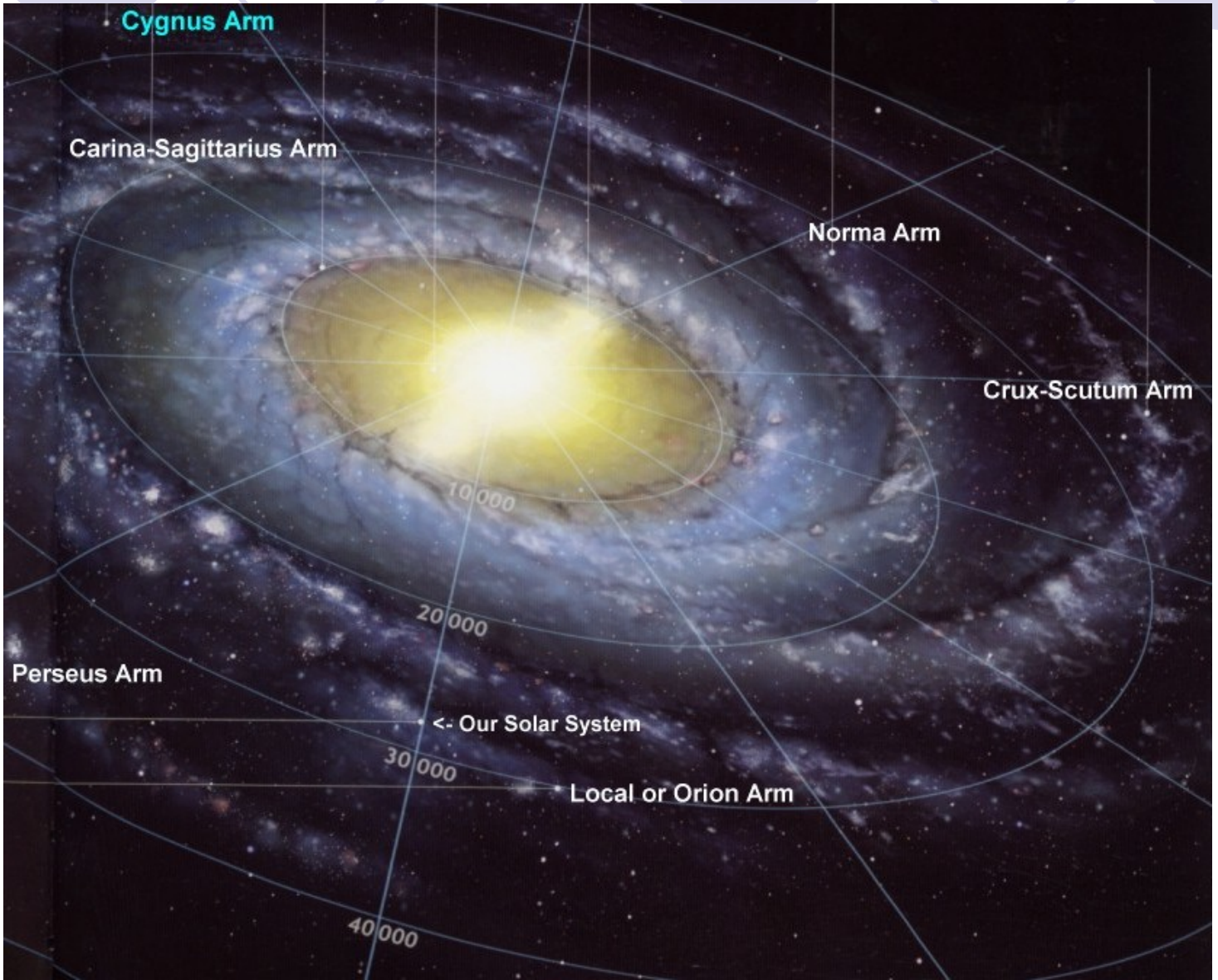


Why a Spiral?

- Recall, that ***differential rotation*** tends to stretch any pattern into a spiral.
- Rotation curve is flat, so stars closer to the center take less time to go around a smaller circle.
- A density wave gets ahead in the central region of a galaxy and falls behind on the outside.

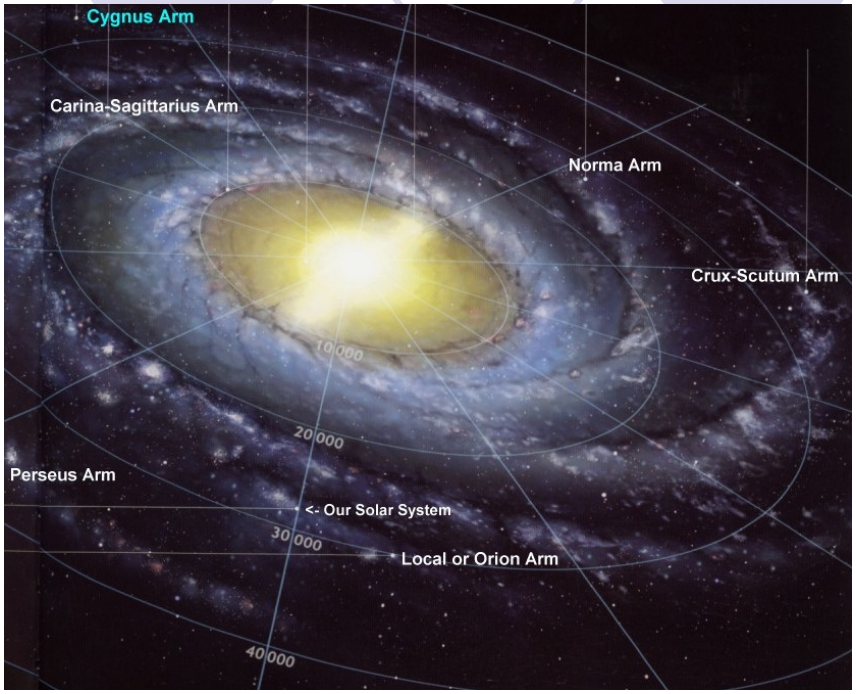


Our Spiral Arms



Which spiral arm did the Sun formed in?

- **A** Orion
- **B** Perseus
- **C** Normal
- **D** Carina-Sagittarius
- **E** Crux-Scutum
- **F** Cygnus



The Grandest Idea in Astronomy

- Waves in the ocean are crested by foam.
- Waves in a galaxy are crested by young stars!